Status Report on Neutrino Factory Acceleration Schemes

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Acceleration Schemes

- Dogbone RLA to 5 GeV
- Linear non-scaling FFAGs, 5–10 GeV and 10–20 GeV
  - Not discussed here
- NuFactJ scheme
- Isochronous FFAGs

Dogbone RLA

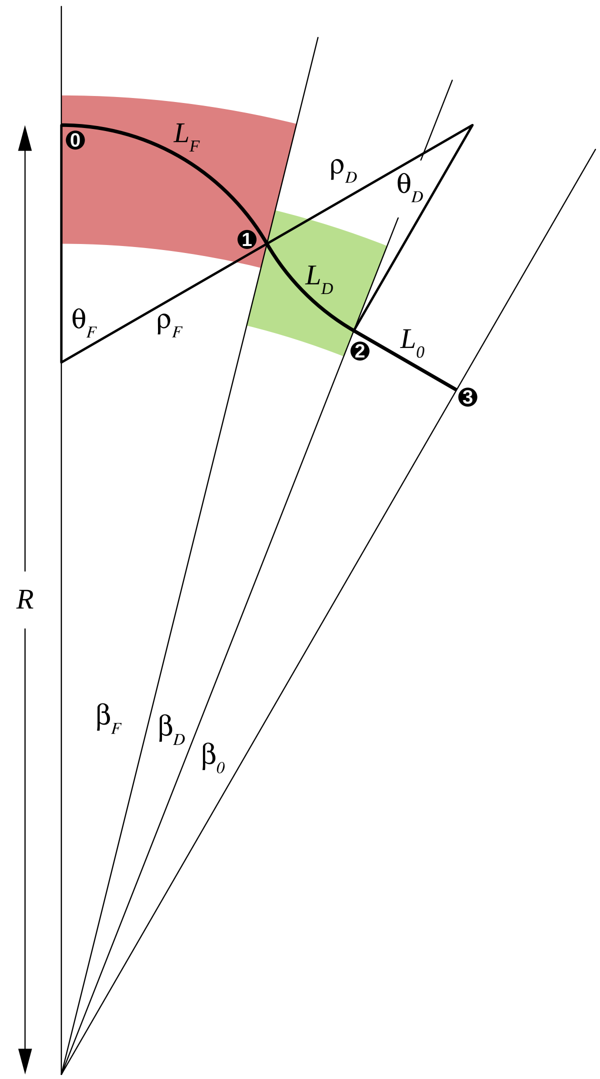
- Full linear design exists
  - Needs to be converted into real terms, costed
  - Compare cost per GeV to FFAGs
- Misalignment and gradient error sensitivity studied
  - Orbit distortion manageable with 1 mm orbit errors
  - Quad fields tolerances 0.2%
- Next steps
  - Add sextupoles to get chromatics right
  - Look at beam with finite energy spread

NuFactJ Parameters

- Need a description of the field in the FFAG
- NuFactJ report: description based on arcs of sector magnets, run in SAD
- Need to convert to

$$B(r,\theta) = B_0(\theta)(r/r_0)^k$$

  $B_0(\theta)$ piecewise constant
- Geometry determined, only specify fields
- For some lattices, no reasonable guess works



Original Table

Lattice number	1	2	3	4	5	6
p_{min} (GeV/c)	0.3	0.3	1	1	3	10
p_{max} (GeV/c)	1	1	3	3	10	20
Cells	32	16	64	32	64	120
Field index	50	15	190	63	220	280
Average radius (m)	21	10	80	30	90	200
Field (T)	1.8	2.8	1.8	3.6	5.4	6.0
β_F (mrad)	26	52	12.7	26	12	6.7
β_D (mrad)	18	36	9.3	18	9	5.3
θ_F (deg)	17	26	10.5	16	10	6.8
Packing fraction	0.45	0.46	0.45	0.45	0.43	0.46
μ_x (deg)	120	131	132	154	157	67
μ_y (deg)	61	103	33	46	23	19
L_0 (m)	2.060	2.120	4.325	3.229	5.046	5.668
$2L_F$ (m)	1.104	1.065	2.041	1.575	2.169	2.685
L_D (m)	0.382	0.367	0.747	0.544	0.813	1.062

My Versions of NuFactJ Lattices

- Try to fit the tunes, assuming those were chosen carefully
- Can't do this by just varying fields: degeneracy due to scaling
- Vary β_F, B_D, keeping β_0 fixed

My Versions of NuFactJ Lattices Parameter Table

Lattice number	1	2	3	4	5	6
p_{min} (GeV/c)	0.3	0.3	1	1	3	10
p_{max} (GeV/c)	1	1	3	3	10	20
Cells	32	16	64	32	64	120
Field index	50	15	190	63	220	280
r_0 (m)	21	10	80	30	90	200
β_F (mrad)	27.24	57.38	13.25	27.68	12.41	8.16
$2r_0\beta_F$ (m)	1.144	1.148	2.119	1.661	2.234	3.266
B_F (T)	1.958	3.078	1.992	3.938	5.978	6.215
β_D (mrad)	16.76	30.62	8.75	16.32	8.59	3.84
$r_0\beta_D$ (m)	0.352	0.306	0.700	0.490	0.773	0.767
B_D (T)	-2.619	-3.950	-2.821	-5.525	-8.040	-11.946
$2r_0\beta_0$ (m)	2.275	2.167	4.334	3.250	5.056	5.672

My Versions of NuFactJ Lattices Magnet Parameters and Cost

- Machine costs are huge (non-scaling FFAGs: $\lesssim$ 100 PB each stage)
- Magnet apertures are large
- Fields are very high
- Note: no cavities in cost!
  - RF systems used
    - 0.75 MV/m average over ring, air gap, 5–10 MHz
    - First ring may be variable frequency
      - New type of magnetic alloy core
    - All this needs more careful specification, R&D, costing
  - RF cost will be a significant additional cost

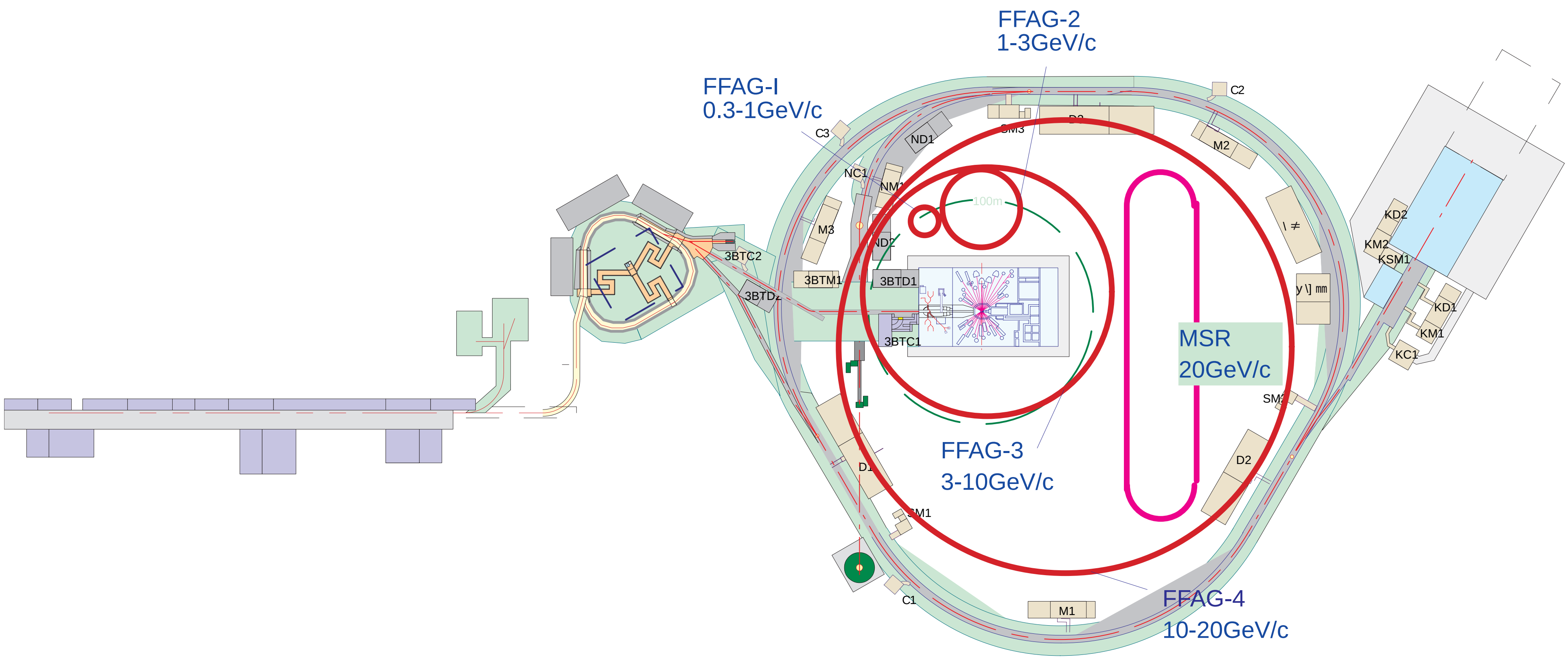
My Versions of NuFactJ Lattices Magnet Parameters and Cost

Lattice number	1	2	3	4	5	6
L_F (m)	1.125	1.088	2.111	1.640	2.225	3.257
r_F (cm)	58.3	75.0	54.1	59.7	52.9	45.0
x_F (cm)	-35.5	-51.6	-32.9	-37.3	-34.0	-41.1
B_F (T)	3.442	4.355	3.292	6.282	9.493	6.567
L_D (m)	0.345	0.288	0.696	0.482	0.770	0.766
r_D (cm)	52.2	67.2	48.1	52.1	47.4	41.2
x_D (cm)	-40.6	-60.5	-40.4	-45.7	-41.4	-48.5
B_D (T)	-3.450	-4.368	-3.387	-6.316	-9.301	-10.783
Cost (PB)	281	355	396	527	1153	1410

My Impressions from Conversations

- These designs were just supposed to by “typical”
- Constrained to fit inside 50 GeV proton ring
- Nobody did anything beyond the SAD model
- RF systems are all R&D projects

FFAGs on Tokai Campus



Lattices from 2002 LBNL FFAG Workshop

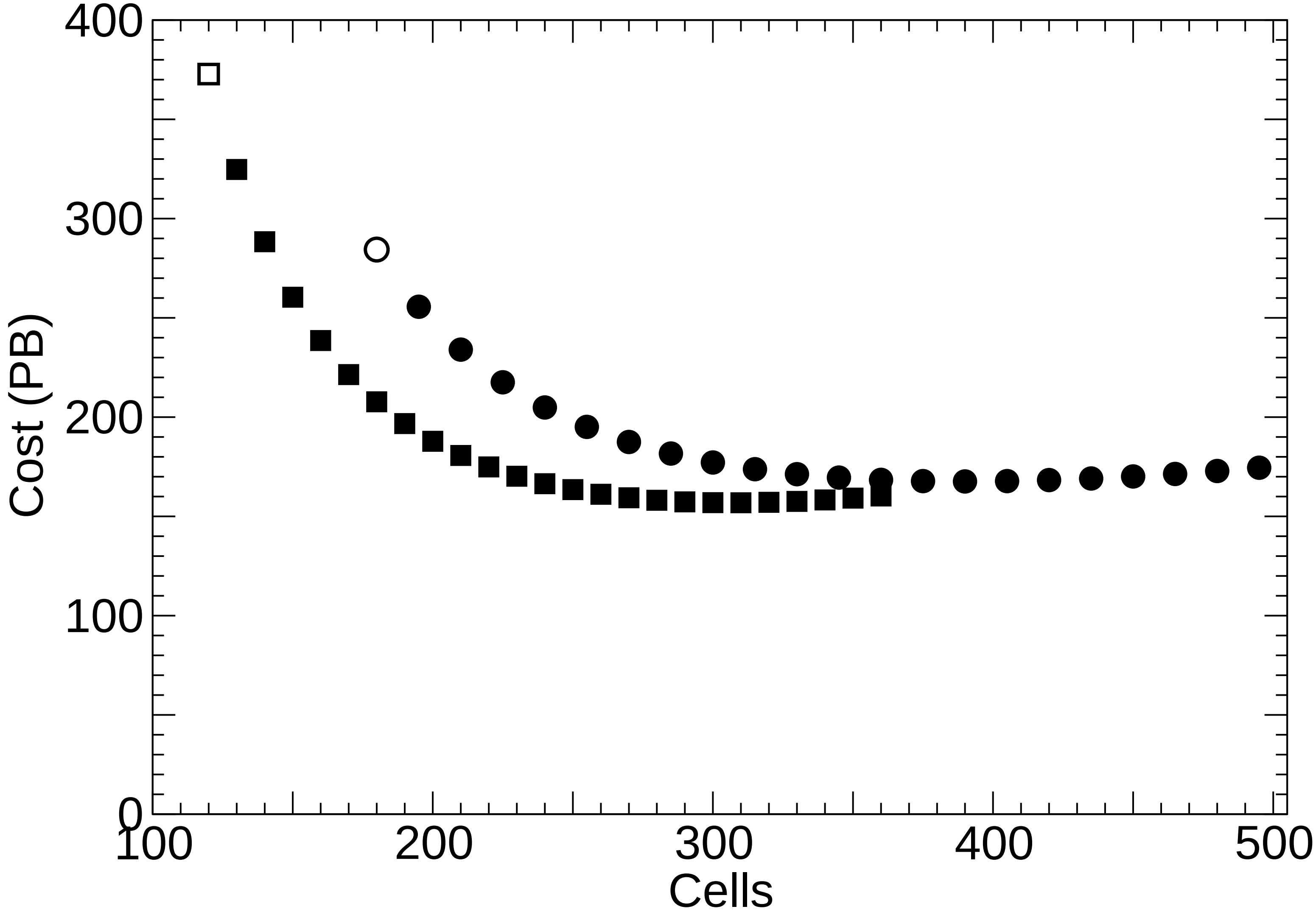
- Work was done on improving the high energy (10–20 GeV/c) FFAG lattice
  - FODO lattice
  - Two versions
    - ⋆ Same number of cells, higher field index, smaller ring
    - ⋆ Larger ring, more cells even higher field index
- I ran the lattices based on a hard edge model
- Cost reduced significantly from NuFactJ design
  - Apertures and fields both much lower
  - Still high
  - Cost can be improved by increasing cells
    - ⋆ Need to fold decays in as usual

Parameters from 2002 LBNL FFAG Workshop

Cells	180	120
Field index	670	330
Reference radius (m)	200	120
Ends (m)	0.30	0.20
D angle (deg)	0.438	0.63
D length (m)	0.93	0.92
D field (T)	5.795	7.738
F angle (deg)	0.562	0.87
F length (m)	1.36	1.42
F field (T)	-3.636	-4.857
Drift length (m)	2.35	1.97

Cells	180	120
L_F (m)	1.362	1.422
r_F (cm)	20.4	23.5
x_F (cm)	1.8	2.0
B_F (T)	7.664	9.764
L_D (m)	0.928	0.918
r_D (cm)	17.8	20.5
x_D (cm)	-10.9	-12.8
B_D (T)	-7.282	-9.560
Cost (PB)	284	373

2002 LBNL Lattice Cost vs. Cells



New Lattices, not Analyzed as Yet

- There is a 10–20 GeV doublet scaling lattice (early 2003)
  - Expect cost improvement
  - Still waiting on specs for this
- Lowest energy lattice corrected to normal conducting
  - Need to work out costing for that
- New proposal by Mori: 10–20 GeV singlet spiral sector
  - Normal conducting, 100 m radius, 50 cm orbit excursion
  - Passive extraction: orbit jump

Next Steps

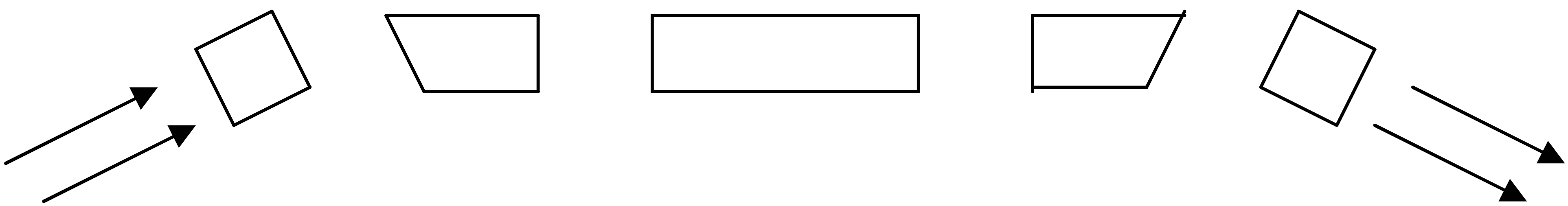
- Need to work out details of a working scheme for all stages
  - Analyze all the schemes I currently have
  - Lattices other than first and last probably need to be defined
    - Optimized to some extent for cost
  - Need to define RF systems
- Need some costing information
  - Normal-conducting scheme at low energy
  - All RF systems
- Start to do more complete simulations

Isochronous FFAG Scenario (Rees)

- Avoid time of flight problems: act like a linac, make machine isochronous
- Two stages: 3.2–8, 8–20 GeV
- Field description
  - Original description based on constructing multiple linear lattices, connecting appropriately
    - Resulting field is nonlinear
  - I fit fields using cubic spline
    - Good fit
    - No excess oscillations
    - Extrapolates well
  - Note highly nonlinear fields

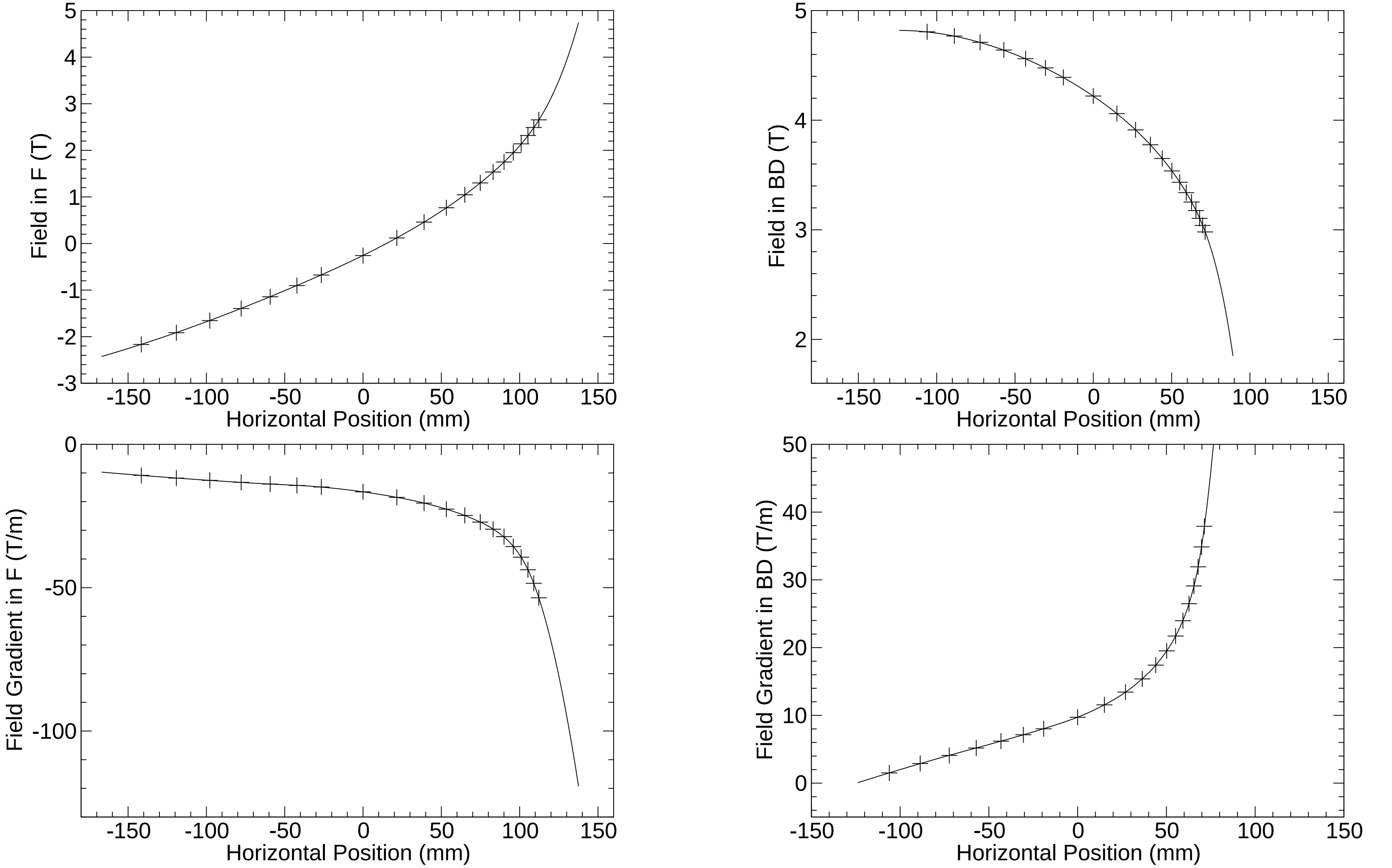
5-Cell Lattice

O bd(-) o F(±) o BD(+) o F(±) o bd(-) O



2.4 0.45 0.5 0.62 0.5 1.26 0.5 0.62 0.5 0.45 2.4 m

Field Fits for Isochronous FFAG



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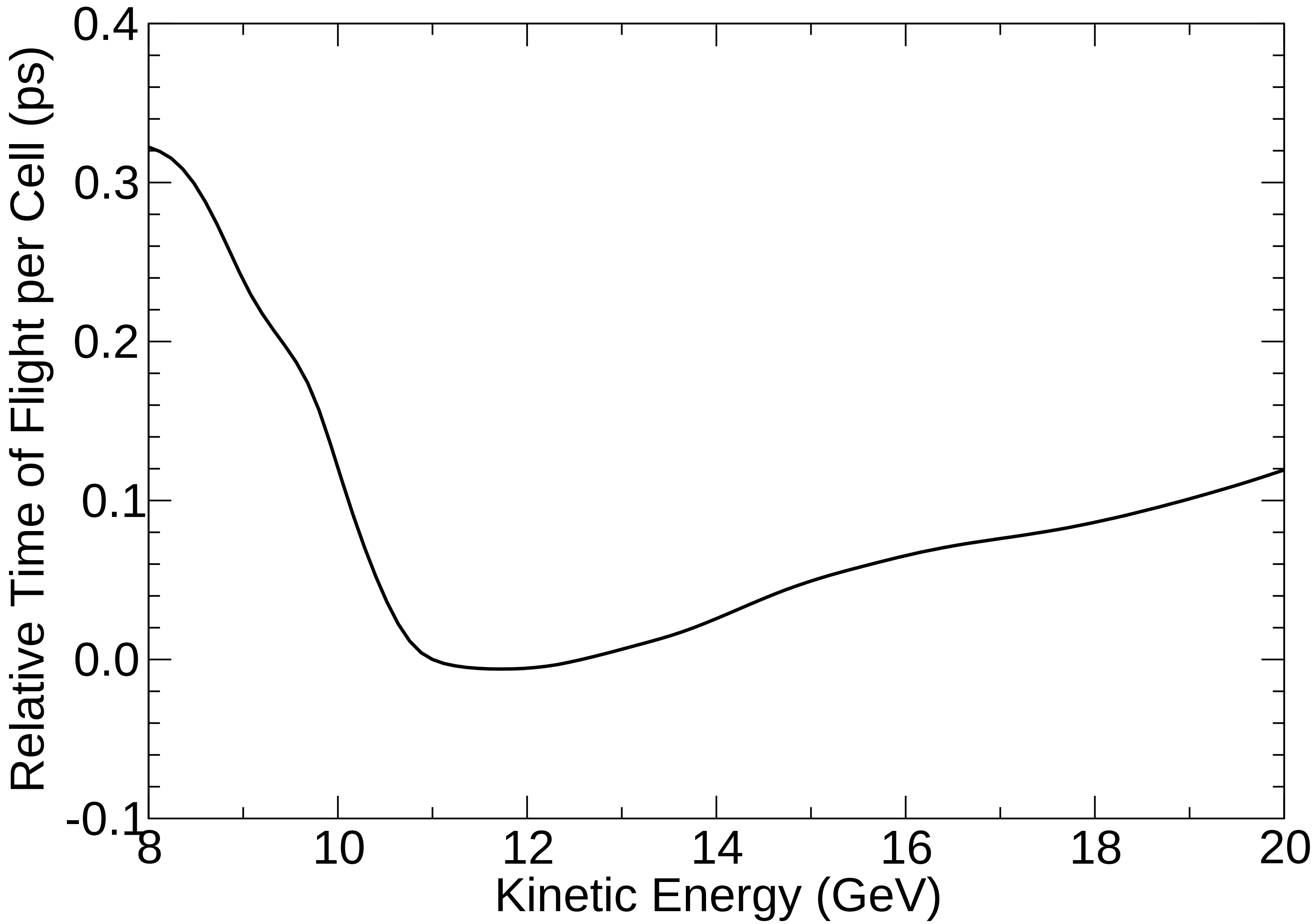
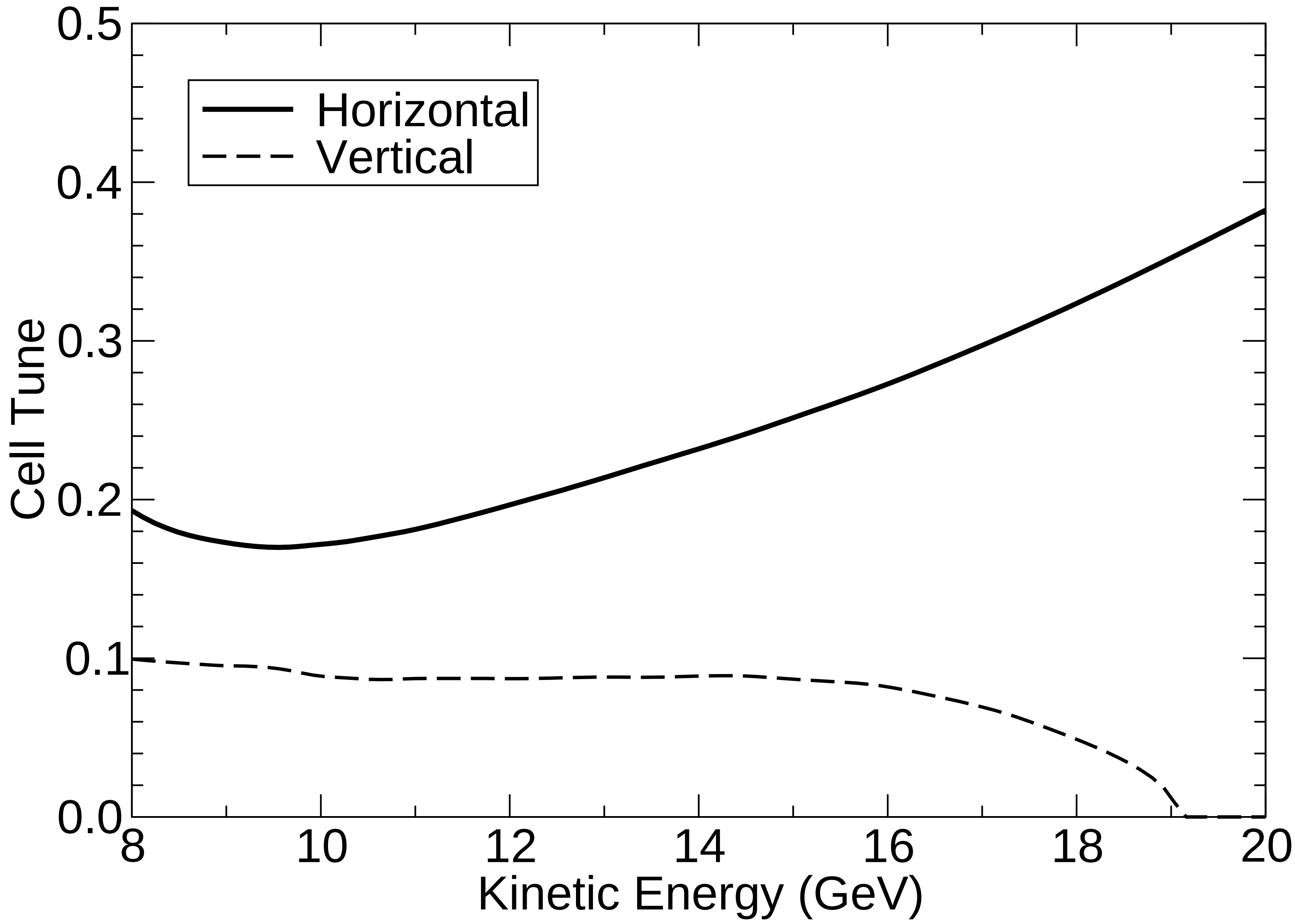
Isochronous FFAG: Analysis

- Time of flight variation is exceptionally small
  - Factor of 10 below natural value
- In my computation, tunes go unstable at high energy
  - Possible cause: Rees uses second-order edge effect which I don’t
- Tracking results (Méot)
  - Beam loss at high energy end
  - Appears to come from hitting a resonance
    - Note it occurs just where I say the lattice goes unstable
  - Highly nonlinear fields at high energy could also be driving it into the resonance

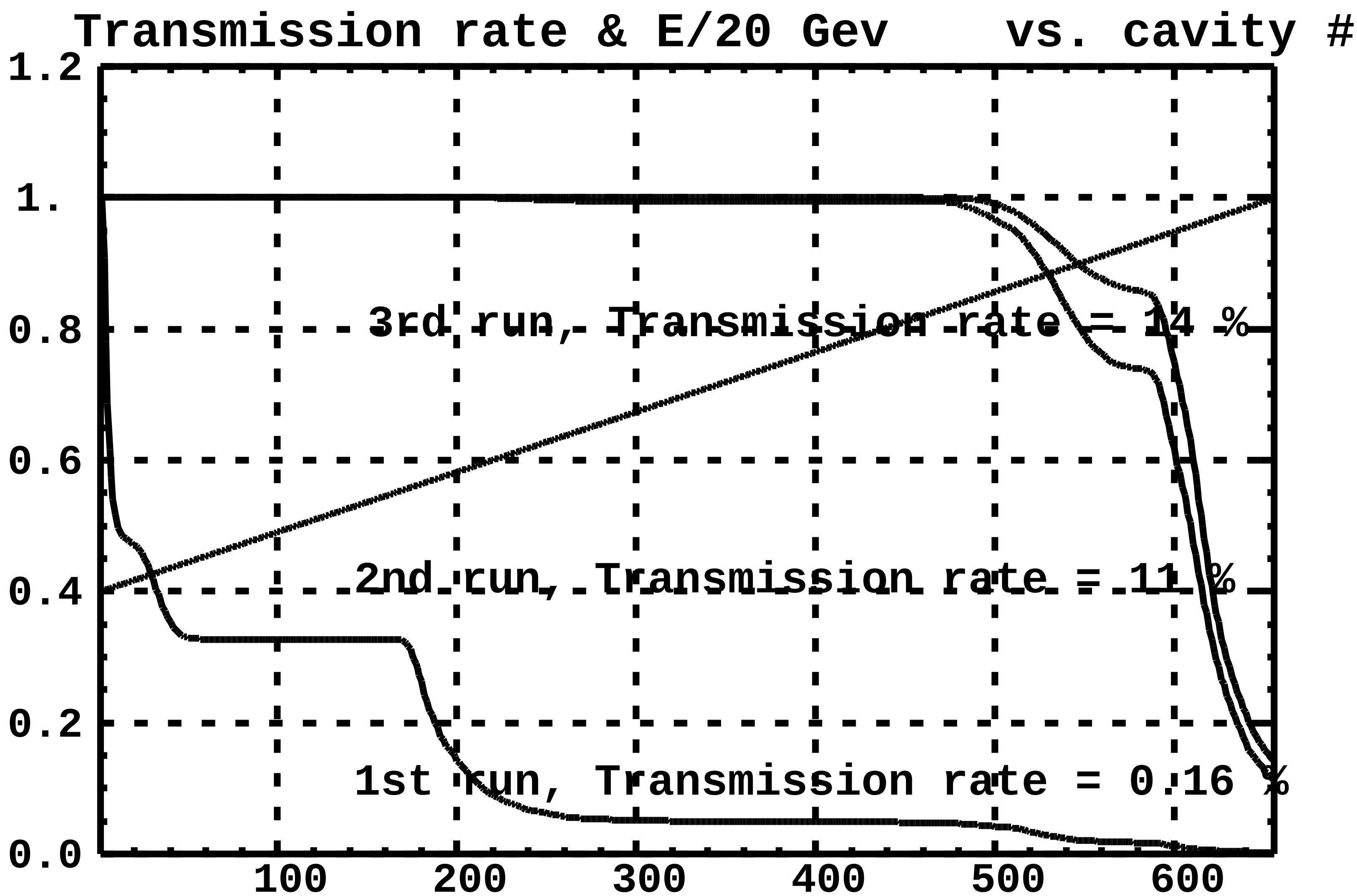
Time of Flight in Isochronous FFAG



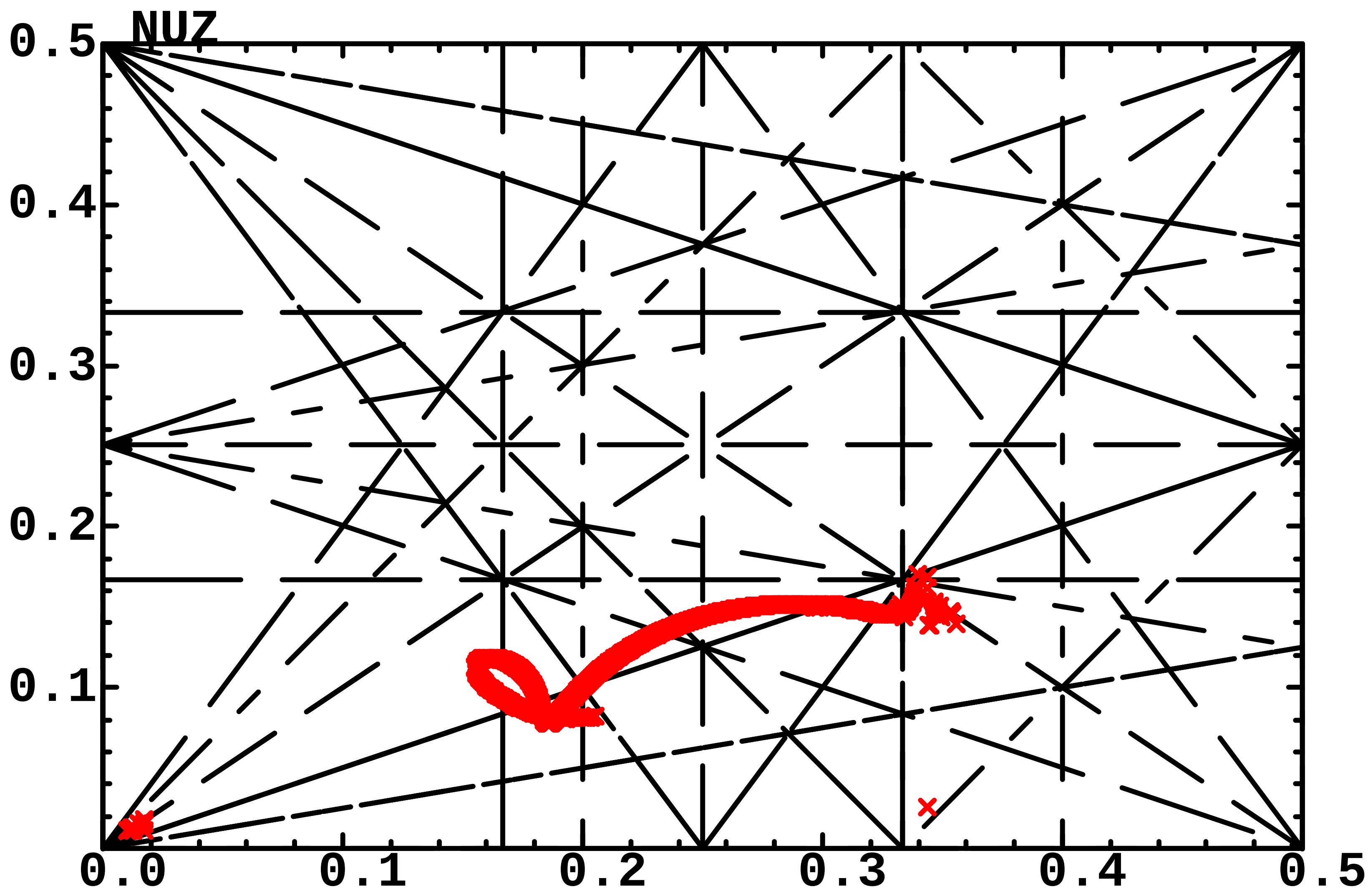
Tunes in Isochronous FFAG



Isochronous FFAG
Beam Loss



Isochronous FFAG
Evolution in Tune Space



Isochronous FFAG Observations, Recommendations

- Machine is very fussy:
  - Tiny changes in lattices (0.1% change in lengths) has substantial effect on time of flight
  - Small end effects give drastic change in tunes
- Probably related to very nonlinear fields, especially at high energy
  - Could possibly relax this: certainly room in time of flight
    - Amplitude dependence of time of flight will give big contribution to TOF anyhow
  - Could consider reducing energy range
- Notice "wiggles" in time of flight
  - More automated design method would take this out
  - May also improve perfomance

Isochronous FFAG
Tasks

- Next, try to do some costing
  - Since lattice unstable at high energy, will have to make guess for beam sizes there.
- Still want to add insertions
  - Short cells in arcs, longer cells in straights to fit RF
  - May reduce cost
  - Matching tricky
  - Get lattice without insertions working first